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Volume equations for *Qualea paraensis* and *Erisma uncinatum* in the north of Mato Grosso state, Brazil

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ABSTRACT: The use of statistical models in the volume estimate is a key tool to reduce time and costs in forest management. This study aimed to apply and select volume model with and without bark for *Qualea paraensis* Ducke and *Erisma uncinatum* Warm., based on data from a forest inventory in Northern Mato Grosso region. A total of 15 models were tested through regression analysis with the following evaluation statistics: standard error of estimate; adjusted coefficient of determination and graphical analysis of residuals. The Spurr model (not linearized) showed the best settings and can be used to estimate the total volume, the trading volume, with and without bark for *Qualea paraensis* Ducke and *Erisma uncinatum* in the north of Mato Grosso state, Brazil.

Keywords: volumetry, cambara, cedrinho.

Equações de volume para *Qualea paraensis* e *Erisma uncinatum* para o norte de Mato Grosso

RESUMO: A utilização de modelos estatísticos na estimativa de volume constitui uma ferramenta fundamental para redução de tempo e custos no manejo florestal. O presente estudo teve como objetivo aplicar e selecionar modelo de volume com e sem casca para *Qualea paraensis* Ducke e *Erisma uncinatum* Warm., a partir de dados de um inventario florestal na região Norte Mato-grossense. Foram testados 15 modelos através da análise de regressão, com as seguintes estatísticas de avaliação utilizadas: erro padrão de estimativa; coeficiente de determinação ajustado e análise gráfica dos resíduos. O modelo de Spurr (não linearizado) foi o que apresentou melhores ajustes e pode ser utilizado na estimativa do volume total, volume comercial, com e sem casca para *Qualea paraensis* Ducke e *Erisma uncinatum* para a região norte de Mato Grosso.

Palavras-chave: volumetria, cambará, cedrinho.

1. INTRODUCTION

Volume equations can be single entry, one variable, or double entry, two variables. Double entry are commonly used, correlating the diameter at breast height and total height, the volume is estimated without the need to fell (CAMPOS; LEITE, 2009). Several authors have published volumetric models settings in different regions of Brazil, among them Scolforo et al. (1998); Schröder et al. (2013); Schneider et al. (2014).

When it comes to native forests, the difficult access to key attributes such as height in closed forests and DBH with buttresses hampers volume quantification. Based on the Sustainable Management definitions of these forests, researchers have adjusted equations for two of the best known species in the Amazon region.

The radial growth of a tree relates to phenology, temperature, precipitation, photoperiod and natural phenomena such as floods and endogenous rhythms (BURGUER, 1980). The entire environment in which the individual is inserted influences its growth in height, DBH, stem form, density, etc..

The *Cedrinho* (*Erisma uncinatum* Warm.) from the Vochysiaceae family occurs throughout the north region, from Mato Grosso to Maranhao state, and also in the Guianas (BIASI, 2005). It has distinctive light-brown heartwood, greyish-white sapwood, low density, medium to coarse texture (IPT, 1983, IPT, 1989a), its wood is of easy planing, sawing and sanding, but it has poor surface finish (IBAMA, 1997a).

The *Cambara* (*Qualea paraensis* Ducke) from the Vochysiaceae family is distributed throughout the Amazon; it is used as plywood, crates, internal use in construction, rafters, beams and floors and is considered heavy (0.78g cm^{-3}), hard and coarse texture (LORENZI, 2002). Common in the gender *Qualea,* individuals need to create mechanisms to survive in soils poor in nutrients and very acidic, with high aluminum content, and they develop great adaptability.

In order to obtain economic, social and environmental benefits, respecting the Sustainable Forest Management Plan - PMFS (Brazilian Forest Service), the objective was to adjust and select volume equations for northern Mato Grosso.

2. MATERIAL AND METHODS

This work was conducted in the cities of Sinop, Porto dos Gauchos and New Parana, in the north of Mato Grosso state. In the inventory carried out in 1981 and 1982, 20 trees of *Qualea paraensis* Ducke and 13 trees of *Erisma uncinatum* Warm. were cubed, Both belonging to the Vochysiacea family.

According to Alvares et al. (2013) classification, the climate is tropical Aw with a dry season in winter, and approximate rainfall of 2,000 to 2,500 mm, mainly occurring from October to March, with a short dry season. The predominant soils in the area are Red and Red-Yellow Latosol, Psament and Red Argisol (IBGE, 2009).

To obtain a volume of 33 trees, researchers the Smalian method, taking measurements of the circumferences with bark at 0.5 and 1.3 m, and later, at every 2 m until the merchantable bole height. To estimate total volume, merchantable volume with bark and merchantable volume without bark, the R software (R Development Core Team, 2015) was used, with the tapeR package, by adjusting 15 volume equations cited in scientific articles, which are described in Table 1.

To evaluate and select the most accurate models, the standard error of estimate in percentage (Syx%), the coefficient of determination (R^2_{aj}) were used, through the equations described below and graphical analysis of residuals and finally, the graphical analysis of the residuals between the actual volume and the estimated volume.

$$Syx(\%) = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)}{n-p}} \cdot 100 \quad (1)$$

$$R^2aj = 1 - \left(\frac{SQ\,Res}{SQt}\right) \cdot \left(\frac{n-1}{n-p}\right) \quad (2)$$

where:
y_i - observed value of the variable;
$\hat{y}_i$ - estimated value of the variable;
n - number of observed data;
p - number of model coefficients;
SQres - sum of squares of residuals;
SQt - total sum of squares.

The Coefficient of Determination (R^2) expresses the amount of the total variance explained by the regression.

As the Coefficient of Determination grows as a new variable is added to the statistical model, the adjusted coefficient of determination (R^2_{aj}.) was used as a criterion for the number of coefficients of each equation. On the other hand, the standard error of estimate in percentage (*Syx%*) informs the average error caused by the use of the model (THOMAS et al., 2006; SOARES et al., 2011).

To correct the logarithmic discrepancy of models using the Natural Logarithm, the dependent variables were submitted to correction by Meyer Index (IM), and:

$$IM = e^{\left[0.5x(Syx)^2\right]} \quad (3)$$

where:
e - Euler's constant (2.718281828...);
Syx - standard error of estimate.

3. RESULTS AND DISCUSSION

After adjusting the equations, there was the analysis of the parameters of the models, and authors selected those who were better in estimating the volume for individual trees.

The estimated regression coefficients for models of total volume, merchantable volume with and without bark; the adjusted coefficient of determination and the standard error of estimate are shown in Table 2, respectively.

In Table 2 and Figures 1, 2 and 3, the tested models generally for total volume showed adjustments to the data higher than 0.80, unlike the adjustments for merchantable volume with and without bark, which generally ranged between 0.30 and 0.79, being higher to merchantable volume without bark.

However, by evaluating the behavior of the distributions of residuals, the equations 2, 8, 11, 12, 13, 14 and 15 were selected preliminarily, as they presented the best adjustments.

Table 1. Volumetric models selected by literature review.
Tabela 1. Modelos volumétricos selecionados via revisão bibliográfica.

Nº	Models	Author
1	v= bo+b1*(d*h)+ε	
2	v=b0+b1*(d*h)+b2*(1/h)+ε	
3	v=b0+b1*(d*h)+b2*(1/h)+b3*(d*h)²+ε	
4	v=b0+b1*d+b2*d²+b3*(d*h)+b4*(d²*h)+b5*h+ε	Meyer
5	v= b0+b1*d²+b2*(d²*h)+b3*(d*h²)+b4*h²+ε	Nasluhd Mod.
6	v= b0+b1*d²+b2*(d²*h)+b3*h+ε	Stoate
7	v= b0+b1*d+ε	Berkhout
8	v= b0+b1*(d²*h)+ε	Spurr
9	v=b0+b1*d+b2*d²+ε	Hohenald-Krenn
10	v=b0+b1*d²+ε	Kopezky-Gehrhardt
11	ln(v)=b0+b1*ln(d²*h)+ε	Spurr2
12	ln(v)= b0+b1*ln(1/d²*h)+ε	Prodan
13	ln(v)= b0+b1*ln(d)+b2*ln(d)²+b3*ln(h)+b4*ln(h)² +ε	Schumacher-Hall
14	ln(v)= b0+b1*ln(d)+b2*ln(h) +ε	Husch
15	ln(v)=b0+b1*ln(d)+ε	

Where: ln = natural logarithm; H = total height (m); d = diameter at 1.30 m above the ground (cm); β_i = model coefficients; ε = random error

Table 2. Coefficients and statistics of the adjustment in equations for the total volume of *E. uncinatum* and *Q. paraensis.*
Tabela 2. Coeficientes e estatísticas do ajuste das equações para o volume total de *E. uncinatum* e *Q. paraensis*.

Nº	R²aj	Syx%	Fcal	Ftab
		Total volume in shell		
1	0.820	44.57	146.70	2.7
2	0.905	32.37	153.40	2.2
3	0.902	32.82	99.56	2.7
4	0.941	25.53	102.90	2.2
5	0.945	24.68	137.90	2.2
6	0.942	25.20	175.60	2.2
7	0.859	39.51	195.10	6.4
8	0.937	4.74	476.70	2.2
9	0.882	36.05	120.80	4.4
10	0.884	35.74	245.30	2.8
11	0.936	13.74	319.80	2.2
12	0.944	13.48	173.60	2.2
13	0.944	13.00	173.60	2.2
14	0.889	18.12	243.80	3.0
15	0.936	13.74	319.80	2.2

Continues on the next page.

Continued Table 2.
Continuação da Tabela 2.

Nº	R²aj	Syx%	Fcal	Ftab
Commercial volume in shell				
1	0.801	44.567	15.93	0.0003745
2	0.892	32.371	24.51	0.000005
3	0.892	61.902	15.82	0.0000028
4	0.884	47.471	20.61	0.0000188
5	0.888	50.724	21.47	0.0000341
6	0.892	49.489	30.21	0.0000046
7	0.899	57.605	57.31	0.0000000
8	0.899	10.778	50.36	0.0000567
9	0.899	45.760	54.97	0.0000001
10	0.899	49.216	89.98	0.0000001
11	0.468	43.004	24.17	0.0273000
12	0.570	40.694	13.85	0.0000549
13	0.572	39.186	13.85	0.0000549
14	0.577	38.339	27.73	0.0000100
15	0.801	44.567	15.93	0.0003745
Commercial volume without shell				
1	0.367	79.55	15.30	2.7
2	0.649	58.25	28.17	2.2
3	0.649	57.85	19.52	2.7
4	0.623	45.14	23.36	2.2
5	0.636	45.40	28.54	2.2
6	0.649	44.07	40.63	2.2
7	0.671	46.99	101.70	6.4
8	0.671	10.70	51.63	2.2
9	0.671	44.04	60.55	4.4
10	0.671	43.89	121.10	2.8
11	0.590	37.74	39.69	2.2
12	0.792	28.26	57.14	2.2
13	0.793	27.25	57.14	2.2
14	0.794	26.72	118.00	3.0
15	0.590	37.74	39.69	2.2

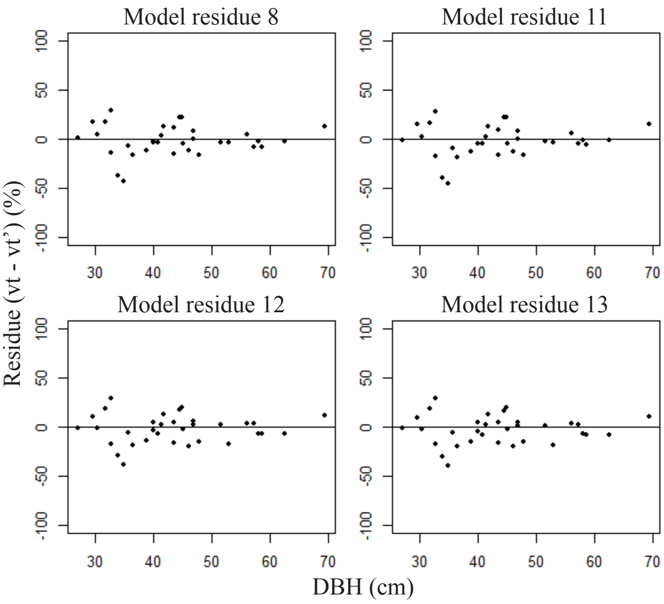

Figure 1. Graphics for the best models that estimate the total volume of trees.
Figura 1. Gráficos para os melhores modelos que estimam o volume total das árvores.

Equation 8, based on Spurr model, had the best estimate for all volumes of *Qualea paraensis* Ducke and *Erisma uncinatum* Warm. For the total volume, the adjusted equation was: Vt = 0.04477 + 0.00041(d²*ht), for merchantable volume with bark, Vc = 0,2469 + 0,00005(d²*ht), and finally for the merchantable volume without bark, Vcsc = 0,3983 + 0,00005(d²*ht).

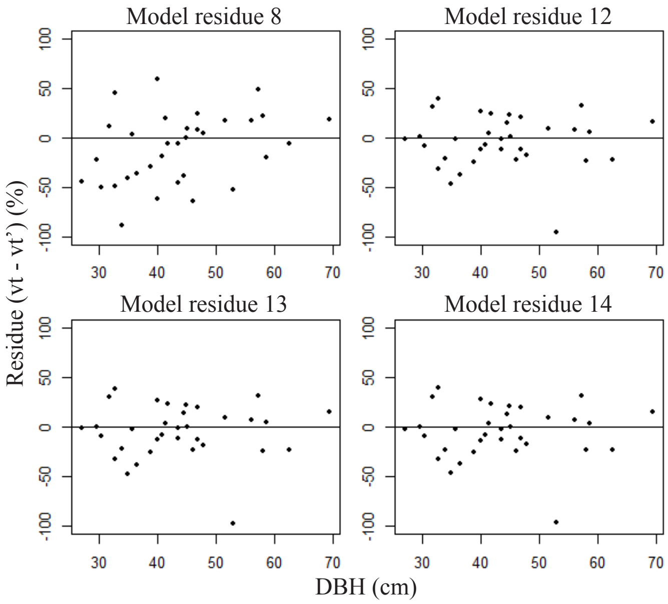

Figure 2. Graphics for the best models that estimate the merchantable volume with bark of trees.
Figura 2. Gráficos para os melhores modelos que estimam o volume comercial com casca das árvores.

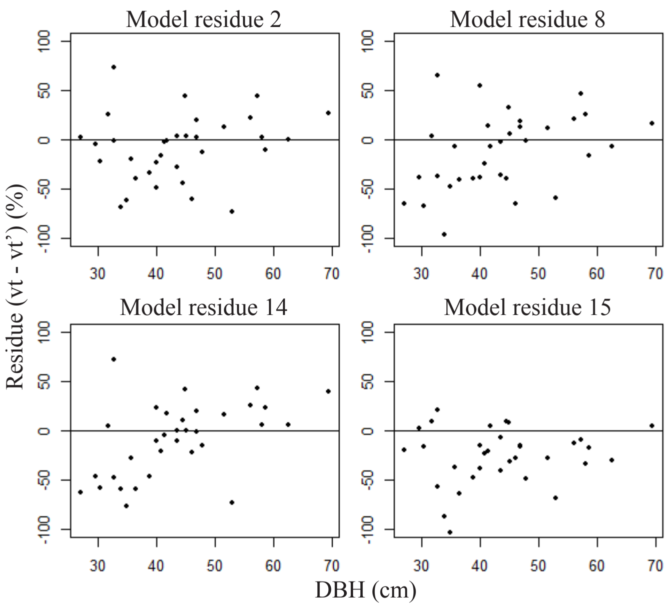

Figure 3. Graphics for the best models that estimate the merchantable volume without bark of trees.
Figura 3. Gráficos para os melhores modelos que estimam o volume comercial sem casca das árvores

Thaines et al. (2010), when testing equations for estimating the volume of many Amazonian species, considered the estimated volume through the Spurr model as the second most adjusted. The coefficients estimated by Thaines et al. (2010) were higher than those of this work, which intensifies the need for application of different volume equations for different Amazonian regions.

As for the standard error of the estimates, all models presented Syx% higher than those presented by Colpini et al. (2009).

According to Rodrigues et al. (2015), the logarithmized models of Schumacher and Hall and Spurr were the most accurate in estimating the total volume for *Vochysia maxima* DUCKE in the Tapajos National Forest, and these models also adjusted well to the data of this work.

4. CONCLUSIONS

The non-linearized Spurr equation is the one with greater precision to estimate the total volume and merchantable volume, with and without bark of *Qualea paraensis* and *Erisma uncinatum* according to the diameter and height of trees.

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